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PYROGENICS, INC.

25-26 50th STREET • WOODSIDE, NEW YORK 11377

SUBSIDIARY OF SPACE AGE MATERIALS CORP

See 1473 in back of Doc.

Interim Progress Report #3
Development & Demonstration Of
Nozzles Using Bulk Pyrolytic Graphite
Jan. 1, 1965 - Mar. 31, 1965

Contract No. AF 04 (611) - 9903

PYROGENICS, INC. 25-26 50th STREET • WOODSIDE, NEW YORK 11377

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AF 04(611)-9903

Interim Progress Report #3
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Nozzles Using Bulk Pyrolytic Graphite
Jan 1, 1965 - Mar. 31, 1965

SUMMARY

This report covers the third quarter effort on the development of nozzles using bulk pyrolytic graphite. The firing data on the first unit has been reduced and indicates an average erosion rate of 0.94 mils/sec. over seventy (70) seconds. The second nozzle was fabricated and fired during this period. The insert was ejected at 51 seconds in a scheduled sixty (60) second firing. The reason for insert ejection this late in the firing has not been fully determined. Average chamber pressure was 662 psi with an average erosion rate of 0.67 mils/sec. over fifty-one (51) seconds. The third development unit, a free standing design has been fabricated and will be fired during the next period. The fourth unit, a heat sink type, is currently being designed.

Introduction

This is the third quarterly report for Contract No. AF 04(611)-9903 concerning the development and demonstration of bulk pyrolytic graphite for rocket nozzle application. The purpose of this contract is to design, develop and test fire under severe solid propellant conditions bulk pyrolytic nozzles to demonstrate their utility and to take full advantage of the unique physical properties of this material. In designing the bulk pyro nozzles, consideration is to be given to four factors in the following order of importance:

1. Weight
2. Performance
3. Simplicity
4. Size

Four development nozzles will be made utilizing four different orientations. These will be selected from eight configurations. These units have a throat diameter of 1.120" and will be fired for sixty (60) seconds at a Pc of 600-700 psia and a T_c of 6500°F. Based upon the results from firing these units, two demonstration units having 2.3" diameter throats will be designed and fired. The firing conditions will be the same except that the burning time will be increased from sixty seconds to one hundred seconds.

FIRST Development Unit

All the test data from the firing of the first development unit have been reduced. The propellant characteristic equation is:

$$\frac{D_{t_2}}{D_{t_1}} = \frac{P_{ch1}}{P_{ch2}}^{\frac{1-n}{2}}$$

where n = 0.6

From the equation we get the following results shown in Table I

TABLE I

Elapsed Time	Erosion Rate	Total Erosion In.
0 - 30 sec.	0.0012 in/sec.	0.0360
30 sec.	Lost 0.0025 in. Layer	0.0025
30 - 40 sec.	0.0009 in./sec.	0.0090
40 sec.	Lost 0.013 in. Layer	0.0130
40 - 70 sec.	0.0006 in/sec.	0.0180
		0.0785 Radial Increase

The diametral increase calculated from the pressure trace is thus 0.157 in. giving a final throat diameter of 1.292, in perfect agreement with the measured diameter of 1.292". The initial throat diameter was 1.135". On this basis the erosion rate over the 70 second period is 0.00094 in/sec. or 0.94 mils/sec. not including layer loss.

SECOND development unit

Fabrication

The second nozzle assembly consists of ten components similar to those used in the first unit plus a chloroprene expansion washer. The Pyroid insert is nested in three HLM-85 graphite components. The arrangements of these components prior to nozzle assembly is shown in Figure 1. Figure 2 shows the insert in place in the graphite nest. Figure 3 is an assembly drawing of the second nozzle showing how the various components fit together. Thermocouple positions are indicated.

The Pyroid insert was produced in the Pyrogenics facility by the SAMCO process at 4000°F ± 30°F. Density of a flat section was 2.18 ± 0.02 gm/cc at 70°F. Throat diameter was 1.127. Visual examination revealed no axial or radial cracks. An X-ray section of the insert, Figure 4, shows normal size laminations in the radial portion of the nozzle, but none in the throat section where there is no curvature.

Firing and Analysis

The second unit was fired at the Atlantic Research test range on March 31, 1965 on an eighteen inch test motor with an end burning configuration.

The duration of the firing was 51 seconds, at which time the insert was ejected from the nozzle. The scheduled firing time was 60 seconds. Maximum pressure was 738 psi average pressure 662 psi. Flame temperature for this metallized propellant is over 6500°F.

The reason for the insert loss so late in the firing has not been determined. It has been noted that the minimum diameter of he insert section that was ejected is considerably larger than the minimum diameter of the remaining exit cone. Insufficient material was found in the test area to be able to reconstruct how the insert passed through the exit cone. No damage was apparent to the exit cone. Those who witnessed the firing saw no particles or pieces in the exhaust flame prior to the ejection of the insert. Both the visual report and pressure trace indicate an extremely smooth firing up to 51 seconds. Viewing the film of the firing may shed further light cn how the insert was lost.

The pressure trace is shown in Figure 5. From this trace and the propellant equation the erosion rate has been calculated as shown in Table II.

TABLE II

Time Sec.	Erosion Rate Mils/Sec.
0 - 10	0
0 - 20	0.2
0 - 30	0.42
0 - 40	0.7
0 - 51	0.67

These erosion rates appear to be quite low for a nozzle insert of this throat diameter and web thickness, using this propellant.

The thermocouple traces are shown in Figure 6. Thermocouples number one and three are reading inlet and exit cone section temperature in HLM85. Thermocouple number 2 is reading temperature behind the insert. Even though this is not an insulating type Pyroid insert, it is noted that the temperature runs considerably under that in the commercial graphite. This is due to the change in the direction of the planes in the exit section of the nozzle. The actual thermocouple locations are shown in Figure 3.

Analysis

A brief thermal analysis was carried out during the last period and results reported in the previous progress report. It appears that the lower temperatures predicted by the calculation were in fact achieved since the erosion rate remained lower for a longer period than would be predicted for a straight washer design.

Stress calculations were completed and it was found that with the original throat insert design extremely high stresses were developed after approximately 10 seconds of firing. A series of stress calculations were initiated to determine what changes could be made in the insert design to reduce the stress to a tolerable level. It was found that the stress could be considerably reduced, if the angle between planes of the throat and the exit section were changed from 30° to 25°. This necessitated the fabrication of anew insert and this was accomplished in time to meet the firing schedule.

It is evident from the firing results that this correction in angle reduced but did not completely resolve the stress problem. Another aspect of the problem which has come to light since the stress calculations were completed is the plastic deformation of pyrolytic graphite in compression at temperatures above 4500°F. Design engineering is of the opinion that a redesign of the insert using the new data and applying it to a larger throat insert would eliminate the excessive stresses that were encountered in the small Number 2 nozzle insert.

THIRD Development Unit

The third development unit was fabricated during this period. Figure 7 is a design sketch of the nozzle indicating the component parts. It should be noted that this unit has only four parts as compared with ten and eleven respectively in units one and two. This is an extremely simple and light weight design which encompasses two advances in the state of the art. The first is the use of edge oriented Pyroid in limited areas in the entrance, throat and exit section. These edge oriented areas, called "knots" by virtue of their appearance, reduce thermal stresses in the first layers by carrying heat to the layers underneath. They also act as mechanical stress relievers by permitting the first layer to expand in those areas where layer cracking has been a problem. There was considerable discussion in design regarding the wisdom of putting knots in the throat section. Maximum thermal stresses occur in the throat which would dictate the use of stres [illegible]lievers in the throat; on the other hand maximum mechanical forces [illegible]ur in this region and it is felt that the use of edge Pyroid here might weaken the throat. However, based on the results of the first firing, layer loss did not occur until over 40 seconds, so relief of thermal stresses was considered more important, and four knots were designed into the throat area.

The second advance is the use of a free standing Pyroid nozzle with a high performance solid propellant motor. This has never been tried before and therefor there has been some hesitation in combining two new concepts in a nozzle at the same time. The decision to incorporate these advances in the same unit has been made because only four development nozzles are called for in this effort and each is to be an entirely different design thus precluding a two step test. In addition, the free standing concept is extremely light and simple, both important objectives in this contract.

Due to the spaciul variation in orientation in this design, a simple stress and heat transfer analysis cannot be undertaken. A meaningful analysis of this nozzle would require a mathematical effort beyond the scope of this contract.

FOURTH Development Nozzle

The number four unit is in preliminary design. This is a heat sink nozzle in the throat section with plane oriented Pyroid in the entrance and exit sections which prevents heat flow into the nozzle for these areas, thus permitting higher heat sink capacity for the throat section. Due to the large radial expansion in this type nozzle, special precautions must be taken in designing a system to accommodate the expansion yet prevent gas leakage around the nozzle. Calculations have been initiated to determine container design.

Future Work

The third development nozzle will be assembled and scheduled for firing. Firing should occur the last week in April.

Design work on the fourth unit will continue so that this unit will fire near the end of the next period.

Layout of the demonstration nozzles (2.3 inch throat) will be initiated and design configurations studied.

Figure 1

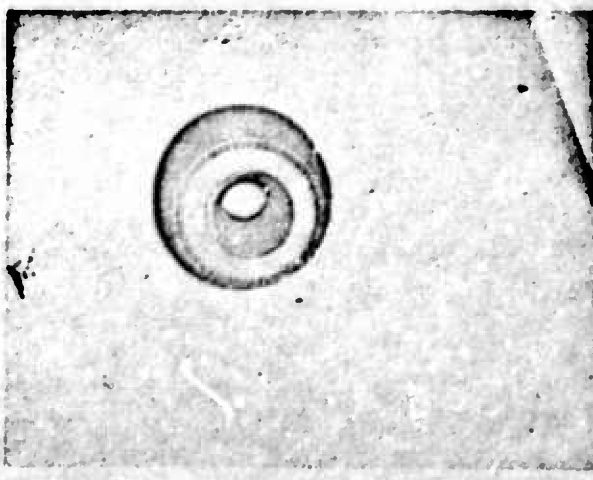
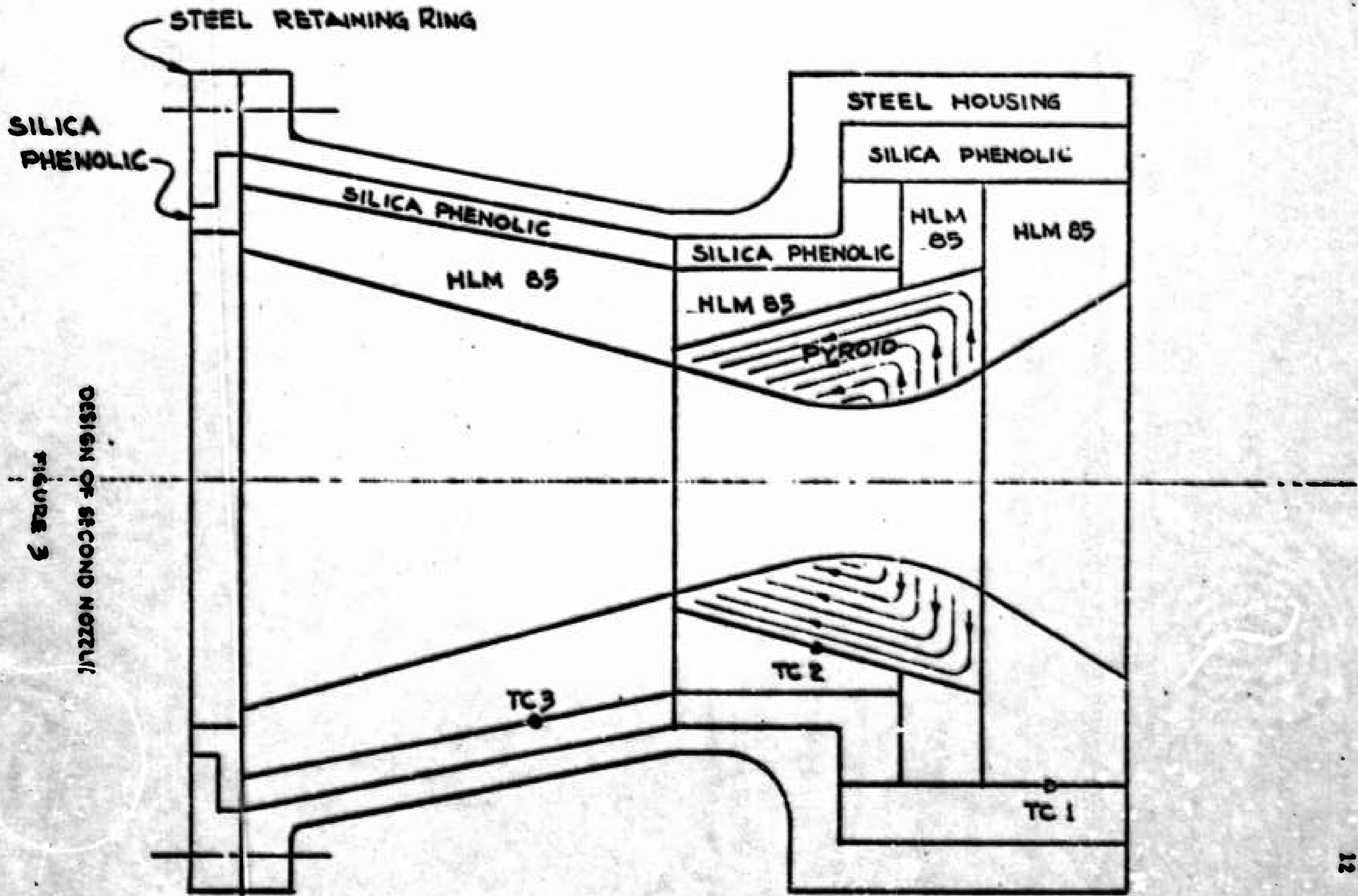


Figure 2



DESIGN OF SECOND NOZZLE

FIGURE 3

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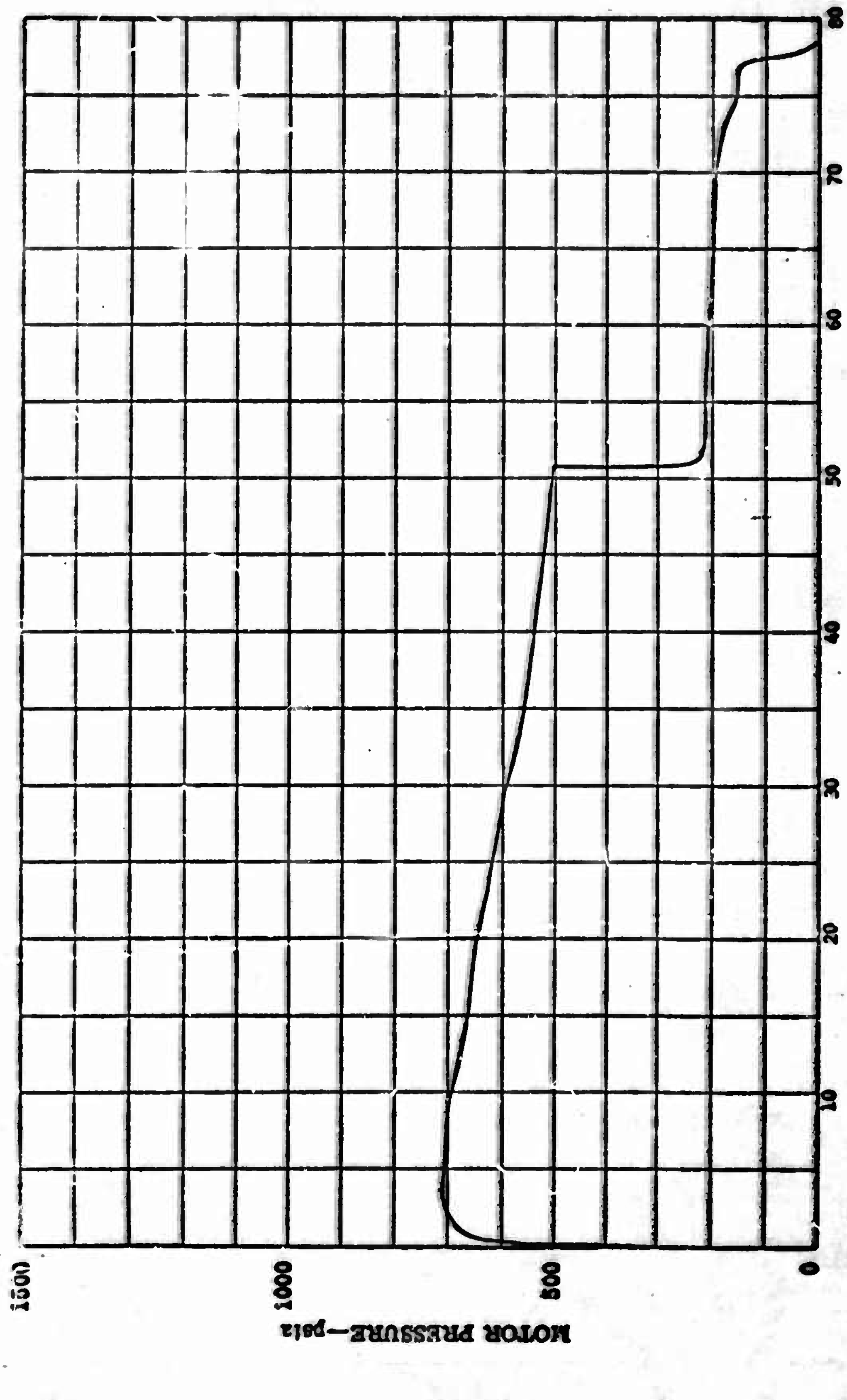
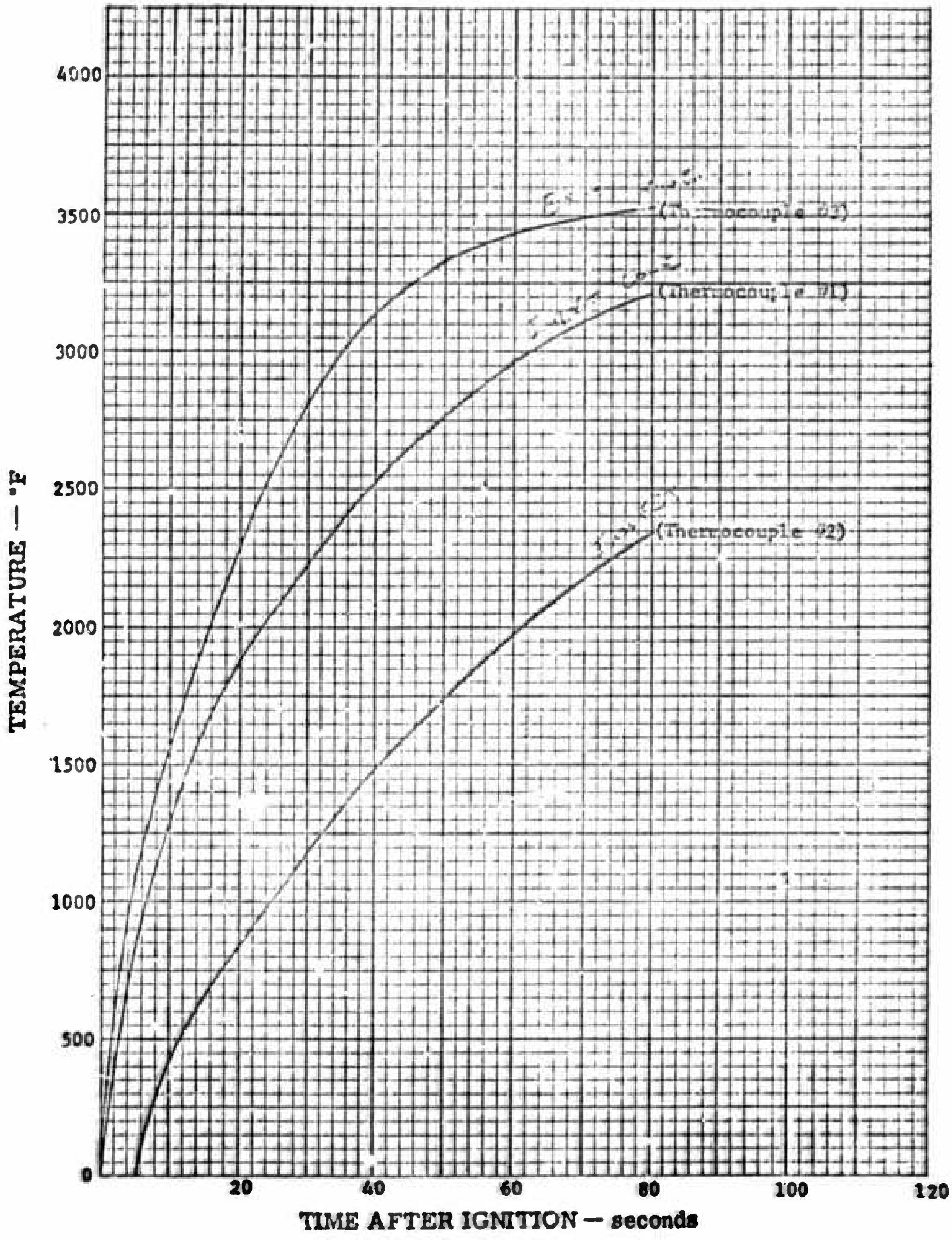
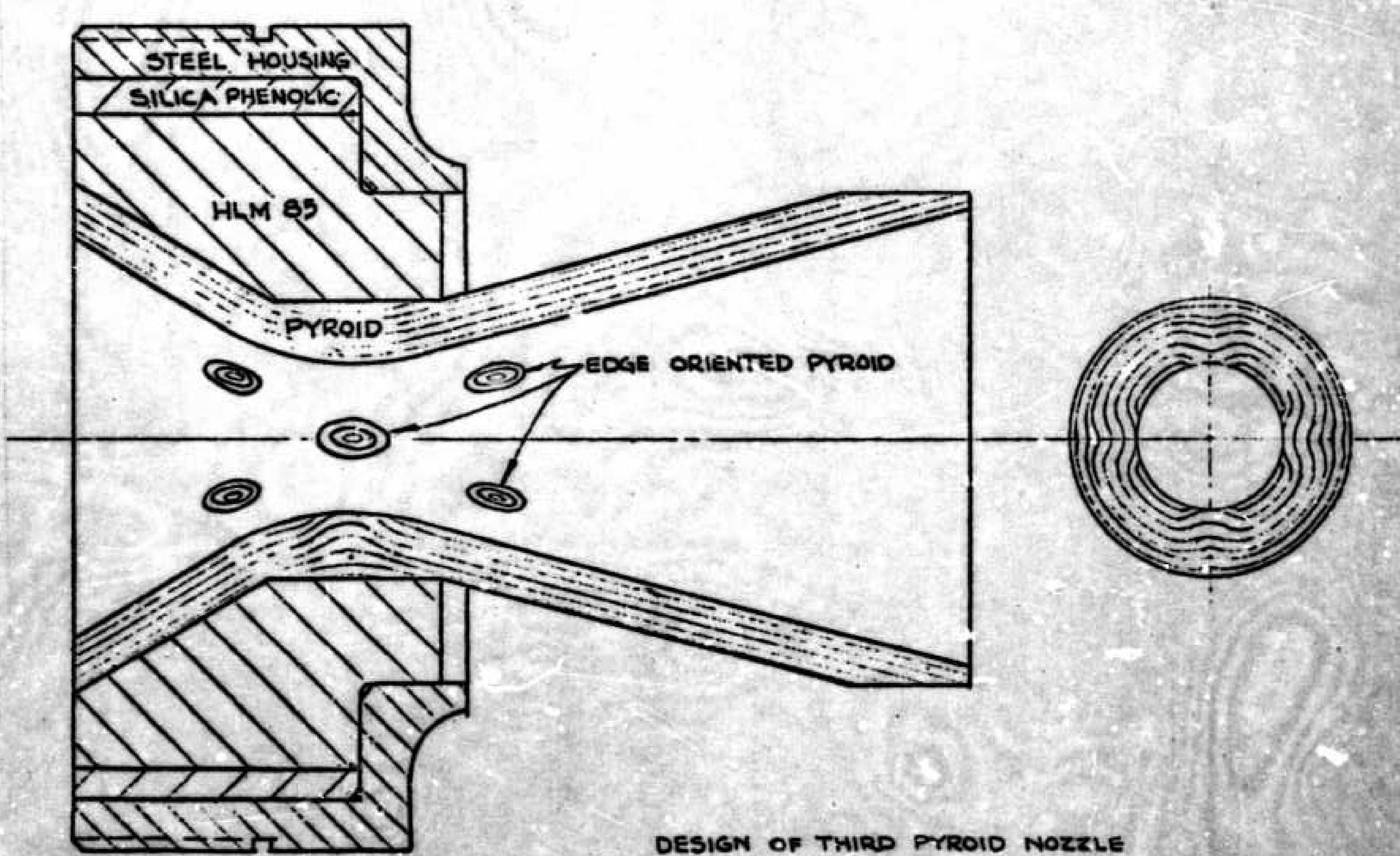


Figure 5. Motor Pressure Trace for Firing sfb-2



Nozzle Insert Temperature
Data Firing SFb-2



DESIGN OF THIRD PYROID NOZZLE

FIGURE 7

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13. ABSTRACT

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